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Numerical Optimization Of SRM With Geometrical Parameters Using Ansys

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Abstract
Switched reluctance motors (SRMs) are have many applications due to their simple and robust structure. SRMs are mechanically and thermally robust, it also has high torque density, efficiency, and reliability, coupled with their fault tolerant structure and low manufacturing cost. Simple concentrated excitation windings are part of stator, and there is no winding or magnet on the rotor. SRMs have too many outstanding qualities but the vibration and acoustic noise of SRMs are main drawbacks and it was caused by the radial forces. The radial forces leads to deformation on the stator yoke, which in turns create vibrations and consequently, frame deformation. When these vibrations resonate with the motor body's natural frequencies, the amplitude of the oscillations and the deformations become very high. Again it leads to very high acoustic noise. The vibration and acoustic noise of SRMs have been deeply studied throughout the years, and various methods are applied for reducing them. This thesis is focused on the acoustic noise reduction techniques by doing changes in the design. There are many methods that focuses on the stator damping effect improvement, radial force reduction and motor natural frequency manipulation. In this thesis, a new acoustic noise mitigation and vibration method is proposed. This method combines the damping improvement and radial force reduction on the stator. By introducing rectangular windows on the rotor and the stator poles reduces the radial forces, which result in a reduction on the stator deformation. Damping elements that are diamond shaped air gaps are inserted into the stator back iron. The number, size, the distance between the elements, and the distance from the stator outer surface to the first air gap are adjusted to achieve the minimum stator deformation and consequently, the minimum acoustic noise. Analyses are performed with 2D/3D electromagnetic and mechanical finite element (FEAs) and vibration analyses tools, and the acoustic noise is reduced successfully.
Key Words: *Switched reluctance motor, radial force, acceleration of vibration, acoustic noise, fluctuation voltage*

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I. Introduction

Introduction of Switched Reluctance Motor Drive System

Switched reluctance machine (SRM) has several advantages like low cost, rugged structure and better fault tolerance. These features make SRM a good candidate of high-speed application like vacuum cleaner [1], stater-generator for aeroengine [2], compressor [3] and automotive traction [4]. Due to high level of acoustic noise and vibrations in SRM, few noise sensitive application are not fulfilled.

Fig.1.1. shows the conventional SRM drive system. It is made of half bridge converter and a SRM. By initiating the winding of one stator phase (Phase A in fig 1.2), SRM rotates from unaligned to aligned position due to the attraction force between rotor and stator. If the rotor passes the aligned position ($dL/d\theta<0$), the tangential force will prevent SRM rotation, SRM runs in generator mode. If the rotor is not in aligned position SRM runs in motor mode. If windings of SRM excited in sequence then rotor rotates continuously. Figure 1.3(a) shows the current waveform for SRM. SRM runs in motor mode because SRM is excited during the ascending region of inductance.

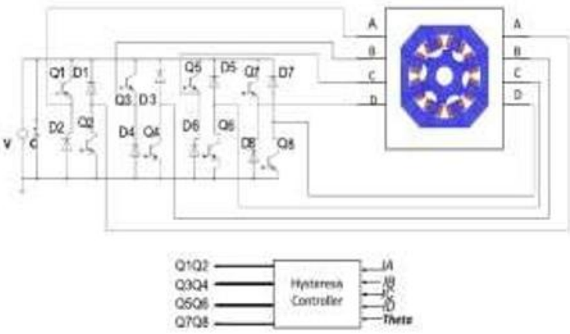
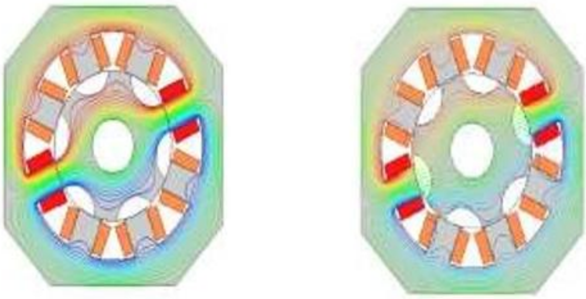
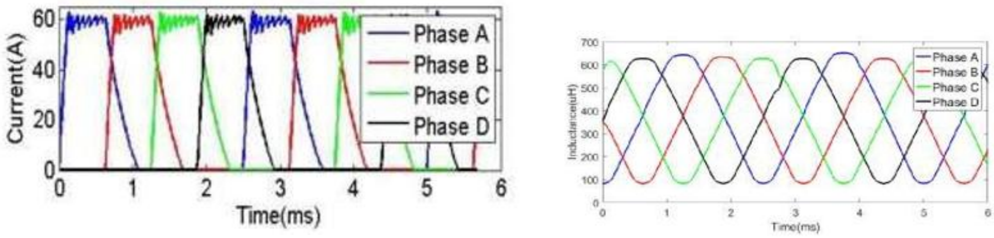


Figure 1.1. Switched reluctance motor drive system



(a) (b)

Figure 1.2. Flux lines at two rotor position(a) Aligned position (b) unaligned position



(a)Current waveform (b) Inductance Profile

Figure 1.3. Current waveform and inductance profile of SRM

Origin of Electromagnetic Vibration in SRM

The electromagnetic vibration caused by radial electromagnetic forces in the SRM is the main focus of this research. SRM is controlled with hysteresis current control strategy. Vibration in stator and motor is caused by current excitation. Relation between Current and radial electromagnetic force is given by the equation 1:

$$F_r = \frac{dW_m}{dx} = \frac{1}{2} i^2 \frac{dL}{dx} \quad (1)$$

II. Literature Review

SRMs have been intensely developed over the last two years. SRMs was not fully implemented earlier because lack of power electronics devices and high switching techniques [1]-[7]. Due to development in motor design and high power switching devices SRM become more attractive for the researchers, academic and industry. SRMs have a high power to weight ratio, low manufacturing cost, high efficiency over a wide range because lack of a permanent magnet and windings [8]. The advantages mentioned above make SRM favourable and attractive for industrial application and researches.

SRMs can address varied and unique requirements like high fault tolerance and speed torque relationship, which make them an ideal choice for electric cars, trains and buses [9]-[14]. Due to high speed capacity and robust nature SRMs are well suited for aerospace [15]. If the SRM's phases are excited at certain rotor angle, movement would be very smooth. Position of the rotor is measured using mechanical sensors. Due to mechanical position sensor's reliability issues increases, it also makes system complex. Sensor-less position estimation estimation method also exists in the literature [16], it's made the system more complex.

SRM gives high level of torque ripple at low speeds at single pulse voltage control mode that is another disadvantage of SRM. The torque ripple is higher in SRM as compared to the sinusoidal AC machines[17]. The torque ripple is mainly due to non linear behaviour of the inductance based on the position of the rotor and the excitation current. Torque ripples causes low accuracy in the servo motors [18]. Torque ripples can be reduced by changing the motor design and improving the control [19]-[21].

III. Objective

Our main objective of the study is to study the effect of providing holes in the stator and rotor, how this is effecting the radial forces and mechanical vibration in SRMs. To maximize the benefits holes can be optimized on the rotor. Vibrations can be reduced by reducing the radial forces. A decrease in the radial force causes the tangential force and torque reduction. While reducing the radial force we have to observe effect on tangential force thus an optimization technique should be introduced. Amplitude of the natural frequencies can be reduced by introducing damping elements to the motor body.

To reduces the radial forces and mechanical vibration in the SRM holes in the stator and rotor lamination are introduced in the SRM. Position of the holes can be optimized for the maximum benefits. Vibration can be reduced by reducing the radial forces. We need to reduce the vibration by reducing the radial forces but it could lead to reducing the tangential forces, so there should be a perfect optimization to control all of the above factors.

IV. Methodology

The analysis and optimization procedure are given for determining the size and position of the distributed air gaps on the stator and rotor. A 4250 rpm, 100kW, 24/16 SRM is selected for the analysis. The natural frequencies are determined through modal analysis of the SRM. The vibration and acoustic noise analysis are discussed.

Analysis procedure

For determining the natural frequencies of the motor, first of all the modal analysis is done. These are the frequencies with which the vibrations coming from the radial forces resonate and that generates high vibrations and acoustic noise.

Electromagnetic, structural, harmonic and acoustic analysis are performed using ANSYS electromagnetic suite and ANSYS mechanical coupled through ANSYS workbench. The electromagnetic analysis is done with Maxwell. The radial and tangential forces on the stator pole tooth tips are analysed. The harmonic response analysis take results from the electromagnetic analysis and determine the acceleration, surface deformation and velocity of the stator in the frequency domain to use for acoustic analysis. One meter microphone test in the transient structural analysis is used to determine the acoustic pressure levels.

Modal Frequency Analysis

Natural frequencies (mode) of the motor are analysed using the modal frequency analysis. Stator poles generates vibration that is caused by radial forces, these forces become more dominant when they resonate with the natural frequencies of the stator. The total deformation on the stator surface increases which amplifies the acoustic sound pressure.

V. Results And Discussion

Modal analysis

The Result of the modal analysis 24/16 SRM is performed using the ANSYS tool, and the results are presented in figures shown below.

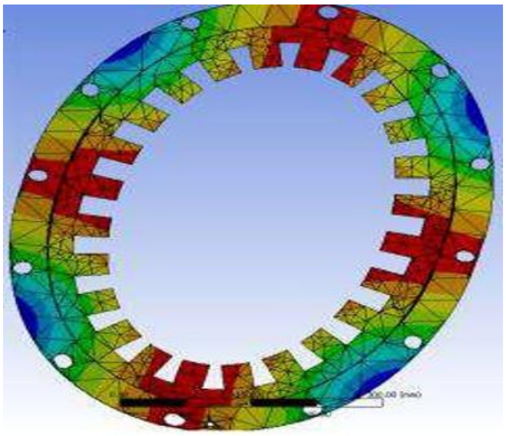


Fig.5.1. Natural frequency (198 Hz) of 24/16 SRM at mode 1

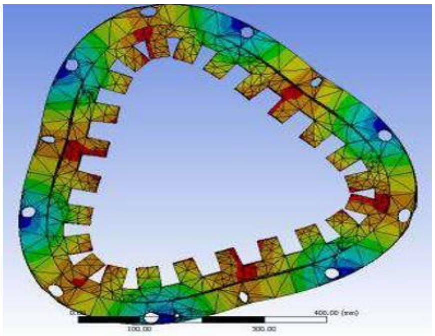


Fig. 5.2. Natural frequency (544 Hz) of 24/16 SRM at mode 2

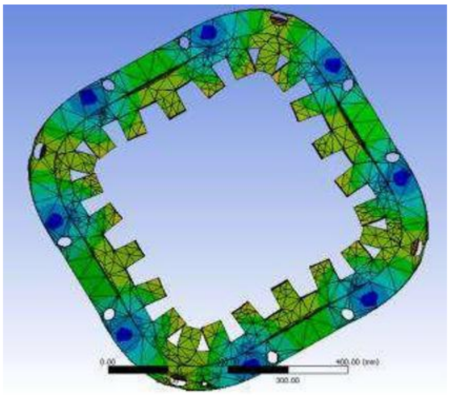


Fig.5.3. Natural frequency (1009 Hz) of 24/16 SRM at mode 3

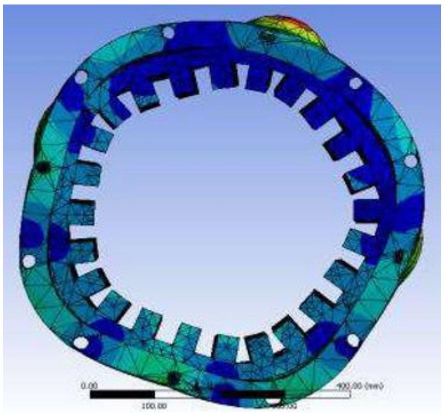


Fig. 5.4. Natural frequency (1568 Hz) of 24/16 SRM at mode 4

Analysis of the distributed Air Gaps

The effect of the distributed air gaps on the stator for various configurations of the air gap patterns and locations are investigated in this section. The air gaps between the stator teeth and back iron have same total area, number and the size are same. Table 5.1. compares the FEA results of the motors that have distributed air gaps on the stator teeth and back iron with the conventional SRM.

Case	Without air gap	Air gap in teeth	Air gap in Back iron
Tavg(Nm)	1136	1142	1132
Peak current(A)	300	500	300
Frad, p-p (N)	1927	994	1678
Total deformation (um)	0.27854	0.25672	0.23867
Total acceleration (mm/s^2)	30880	28653	25581

Table 5.1. Comparison of the distributed air gap locations

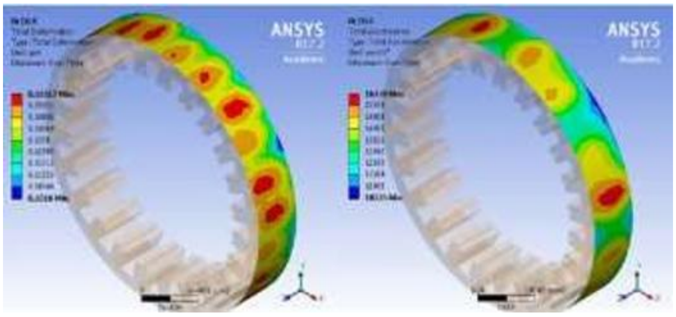


Fig 5.5 Total deformation an acceleration of the optimized SRM.

Summary

Placement of the distributed air gaps on the stator back iron in combination with the single holes in the stator and rotor poles is proposed and analysed. Distributed air gaps have diamond shapes. These diamond shaped air gaps act like series-parallel connected springs and damp the oscillations. Therefore, the total deformation and acceleration of the stator outer surface are reduced. The conventional and proposed SRMs are tabulated for comparison purposes in Table 5.3.

Type of SRM	T_{avg}(Nm)	Peak current(A)	Frad, p-p (N)	Total deformation (um)	Total acceleration (mm/s^2)
Conventional SRM	1136	1927.33	0.5890	0.27854	30880
Windowed SRM	878.7	613.77	1.4316	0.17811	18385
Windowed SRM with Distributed air gap	872.6	692.12	1.2607	0.16317	16338

Table 5.2. Comparison of conventional, windowed and distributed air gap SRMs

The total deformation is reduced 36% with the optimized windowed machine and 41.4% with the optimized windowed and distributed air gap machine. The total acceleration is reduced 40% with the optimized windowed machine and 47% with the optimized windowed and distributed air gap machine.

VI. Conclusion

This paper proposes an acoustic noise and vibration mitigation technique for SRM. SRMs have high vibrations, high torque ripples and high acoustic noise. the proposed acoustic noise and vibration reduction method is introduced. The proposed method combines the radial force reduction and the introducing damping elements on the stator. A damping element is a group of diamond shaped holes distributed on the stator back iron. The reason for diamond shape selection is that it generates zigzag shaped bridges along the stator back iron and these zigzag shaped bridges can be considered as a spring network. The variation in the diamond shape sizes, positions, and the distance between the elements affect the spring constants. Consequently, the damping and the motor's natural frequencies are affected. Thereby, diamond shape sizes, positions, and the distance between the elements are optimized for minimum total deformation and total acceleration on the stator outer surface while having less than 20% average torque reduction.

The proposed method is applied to a 100 kW, 24/16 SRM using coupled electromagnetic and structural finite element analysis (FEA) software packages from ANSYS. The combination of distributed air gap with the hole placement in the stator and rotor is proposed and analyzed. The dimensions and the placement of the holes are optimized to reduce the vibration and deformation without significantly impacting the torque production. The performance index developed as average torque over peak-to-peak radial force variation ($N = T_{avg} / F_{rad.pp}$) is , improved from 0.589 to 1.26.7 with the optimized design, and consequently, the total deformation on the stator surface is reduced by 47 %.

In conclusion, the proposed method provides satisfactory acoustic noise and vibration reduction without having an intolerable effect on the torque production. Moreover, the method does not require a complicated manufacturing process, as it only requires the insertion of rectangular and diamond-shaped holes into the stator and rotor laminations.

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